Comparison of Different Topology of Wireless Mesh Acess Network Using Cross Layer Solution for Performance Improvement

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Abstract

A Wireless Mesh Network (WMN) consists of a three tier network that provides access to the internet consisting of clients and routers. The range of router is greater than that of the client in the Wireless Mesh Network. This causes link asymmetry, and leads to degradation in network performance. The link asymmetry causes three main problems, Unidirectional Link problem, Heterogeneous Hidden Terminal problem and Heterogeneous Exposed Terminal Problem. Cross-layer design is a promising method to satisfy the network requirements .Since multihop path is used to establish reverse path between the client and the router, collision is found to occur in the wireless mesh backbone of the Wireless Mesh Network. This collision has to be avoided to improve the performance of the network .Carrier sense is often used to regulate concurrency in wireless medium access control (MAC) protocols, balancing interference protection and spatial reuse.

Keywords

WM; Cross-layer Design; Carrier Sense

Introduction

A Wireless Mesh Network consists of a three tier network that provides access to the internet. The mesh networks enable new and exciting applications but also pose significant technical challenges due to the need for decentralized control, dynamic topology and the characteristics of the wireless channel. The range of router is greater than that of the client in the Wireless Mesh Network. This causes link asymmetry, and leads to degradation in network performance. The link asymmetry causes three main problems, Unidirectional Link problem, Heterogeneous Hidden Terminal problem and Heterogeneous Exposed Terminal Problem.[1] [2]

Cross-layer design is a promising method to satisfy the network requirements. While the mesh networks exhibit much promise, they also pose some significant design challenges. Despite the challenges posed, the various network requirements need to be met. The implementation of network as a hierarchy of layers that are independent and non-cooperating are unable to take advantage of the interactions between the layers. The approaches were optimizing each layer by itself when a joint optimization across the various layers of the network would have resulted in greater network performance.

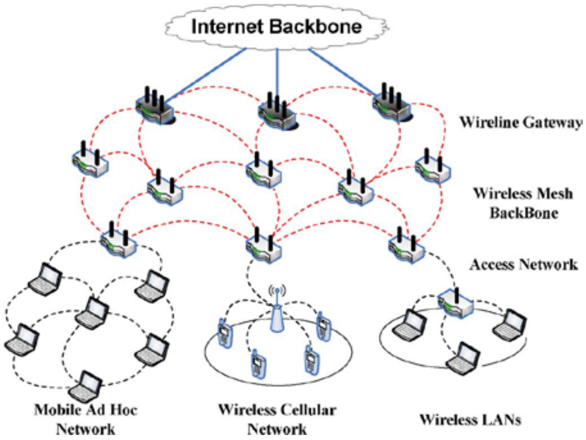

FIG. 1 WIRELESS MESH NETWORK [1]

To meet the requirements of energy constraint, bandwidth constraint and delay constraints, a cross-layer protocol design that supports adaptivity and optimization across layers of the protocol could be implemented. In an adaptive cross-layer protocol stack, the link layer can adapt rate, power, and coding to meet the requirements of the application given current channel and network conditions. The Medium Access Control (MAC) layer can adapt on underlying link and

interference conditions as well as delay constraints and priorities. Adaptive routing protocols can be developed based on current link, network, and traffic conditions. It has been shown that cross-layer networking can improve performance by as much as a factor of two. [1]

Improving the MAC layer in ad-hoc wireless networks is essential if we need to maximize the network efficiency and to reduce collision. Carrier Sensing could be used so as to improve the performance in addition to the cross-layer approach. [3]

The remainder of this paper is organized as follows. Section 2 presents the problems associated with WMN. Section 3 presents cross-layer approach and the carrier sensing included in addition to cross-layer. Section 4 discusses cross-layer under different topology and inclusion of cross-layering in random topology. Section 5 presents simulation results indicating the improvement in network performance with cross-layer and carrier sensing. Section 6 concludes the paper.

Problems in Wmn

The mesh backbone and access network uses IEEE 802.11 protocol. Link asymmetry arises between mesh router and clients due to variable transmission range of nodes and this affects the network performance. The link asymmetry raises the following three problems: *1) Hidden node problem, 2) Exposed node problem, 3)Unidirectional link problem* [1]

Hidden Node (HN) Problem

Hidden nodes are the nodes that are not in the range of other nodes or a group of nodes. Each node is within communication range of the access point, but nodes cannot communicate with each other as they do not have physical connection to each other. IEEE 802.11 uses 802.11 RTS/CTS acknowledgment and handshake packets to partly overcome the hidden node problem. . RTS/CTS is not a complete solution and may decrease throughput even further, but adaptive acknowledgements from the base station can help too.[3]

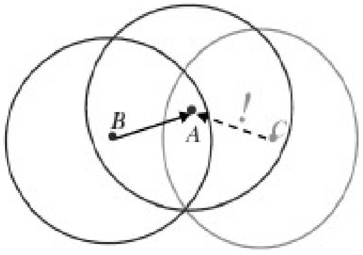

FIG. 2 NODE C REMAINS HIDDEN TO NODE B

Exposed Node(EN) Problem

In wireless networks, the Exposed Node Problem occurs when a node is prevented from sending packets to other nodes due to a neighboring transmitter. IEEE 802.11 RTS/CTS mechanism helps to solve this problem only if the nodes are synchronized. When a node hears an RTS from a neighboring node, but not the corresponding CTS, that node can deduce that it is an exposed node and is permitted to transmit to other neighboring nodes. If the nodes are not synchronized, the problem may occur that the sender will not hear the CTS or the ACK during the transmission of data of the second sender.[3]

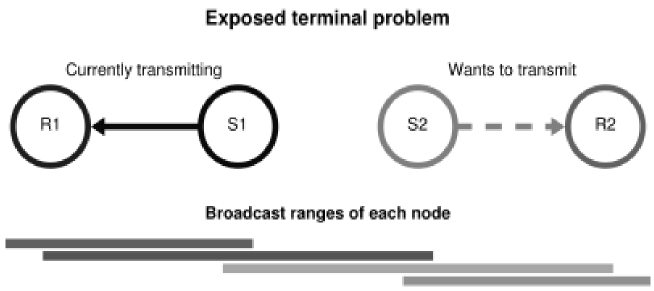

FIG. 3 NODES S2 AND R2 REMAIN EXPOSED TO NODES R1 AND S1

Unidirectional Link Problem

This refers to the problem in which clients with small transmission range cannot respond to routers after receiving requests from routers.

OUR APPROACH TO SOLVE LINK ASYMMETRY

Cross-layer Approach

In order to simultaneously address the three problems, unidirectional links need to be eliminated. However, eliminating unidirectional links is not a simple task, as the chance of the mesh router to access the channel should not simultaneously increase. Thus, channel should be accessed by routers and clients without causing collisions and thereby not affecting network performance. The solution should consider the cross-layer design as well. This is because the three problems raised by link asymmetry is covered by both the network layer [4][5][6] and the link layer[7]. Existing approaches in the network layer and the link layer cannot completely address these problems and the desired approach needs the cooperation between the network layer and the link layer, i.e., the MAC protocol needs the topology information obtained in the

network layer, and the routing protocol needs the MAC protocol to directly address the unidirectional link problem. [1]

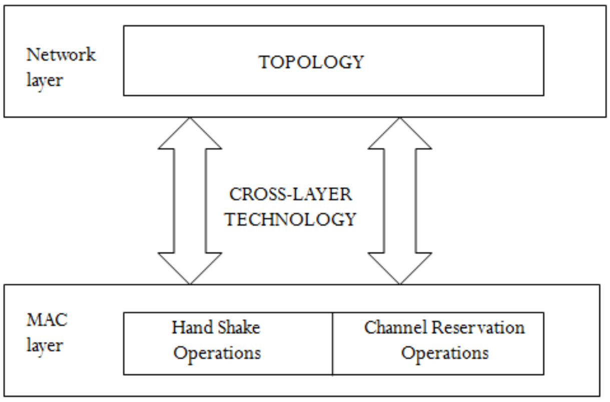

FIG. 4 CROSS-LAYER APPROACH

In cross-layer approach, new control frames are introduced: 1) delay to send (DTS) and 2) negative ACK (N-ACK). DTS is used to avoid collision on demand by canceling the transmission of a heterogeneous hidden terminal. N-ACK is used to request the source node to retransmit DATA when collision occurs on the data channel. Based on mechanisms provided in the network layer and the link layer and their interactions, three mechanisms to address the unidirectional link problem, heterogeneous hidden problem, and heterogeneous exposed problem, respectively are introduced. In particular, the unidirectional link problem is solved by routing clear to send (CTS) via multihop mesh clients, the heterogeneous hidden problem is solved by routing DTS on demand, and the heterogeneous exposed problem is solved by processing CTS from the mesh router, depending on whether the mesh router is a bidirectional neighbor or not.

To address the Unidirectional Link Problem a reverse path should be established between the mesh routers and mesh clients. A multihop routing reserve path need to be established, as the range of the routers are greater than that of the mesh clients.

There are three basic handshake operations in our approach. RTS/CTS/DATA is used to handle normal data transmission. When a node needs to send DATA, it first checks the data channel and the control channel. When both channels are idle and the idle time lasts longer than the period of time that is equal to short inter frame space, RTS can be transmitted via the control channel. By receiving RTS, if the channel condition allows it to receive DATA, the destination node promptly replies to RTS by CTS. After receiving CTS from the destination, DATA is sent from the data channel. RTS/DTS/Backoff/. . . /retransmit is used when the channel condition of the destination does not meet the requirements for receiving DATA. After receiving DTS from the destination, the source node will delay its data transmission and retry after backoff. This way, the chance of collision can be largely reduced. RTS/CTS/DATA/N −ACK/Backoff/. . . /Retransmit is used to provide the reliability for DATA transmission. When collision occurs on the data channel, the destination will send N-ACK to the source. After the backoff procedure, retransmission will recover the collided DATA frame.

Along with the basic handshake operations, channel reservation operations are also performed in our protocol. To this end, the network allocation vector (NAV) as a period of time is used to determine how long the channel will be occupied. Each node maintains three NAVs. In particular, NAVC is used to monitor the control channel. When NAVC is positive, transmitting control frame is forbidden. NAVS and NAVR are used to manage sending and receiving operations on the data channel, respectively. RTS is not allowed to transmit when NAVS is positive, whereas data receiving is forbidden when NAVR is positive. Each control frame is appended with a Duration field to support channel reservation. Based on handshake operations, when handshake is conducted on the control channel, the duration information appended in each control frame can be used to update three NAVs (i.e., NAVC, NAVS, and NAVR) for channel reservation.[1]

1) *Addressing Hidden Terminal Problem*

The main idea behind solving the heterogeneous hidden terminal problem is to route the control frames, which can either block or delay the transmission of the router. There are two schemes in order to solve the heterogeneous hidden terminal problem. One scheme involves increasing the coverage of CTS sent by the client. The second scheme is to delay the transmission of router on demand, this scheme involves low overhead. The second scheme is based on the fact that collision occur only when the heterogeneous hidden terminal access the channel while the client is receiving the DATA. The client senses any collision by listening to the control channel. When RTS from the router is received by the client on the control channel while it is receiving DATA, the client ensures that the DATA transmission from that router will collide

with the DATA to be received. In this case, DTS is forwarded via a multihop path through mesh clients to the heterogeneous hidden terminal, i.e., the router, to cancel its current data transmission.

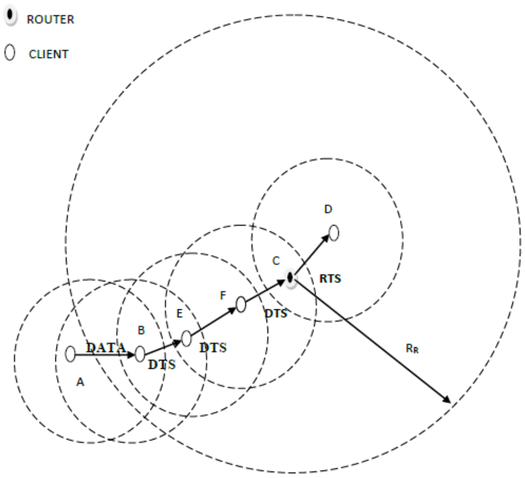

FIG. 5 WMN WITH SOLUTION FOR HIDDEN TERMINAL PROBLEM

2) *Addressing Exposed Node Problem*

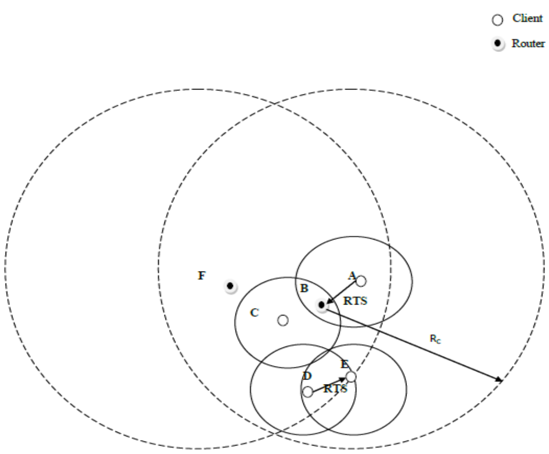

FIG. 6 WMN WITH SOLUTION FOR EXPOSED TERMINAL PROBLEM

The range of routers are large, due to this the CTS frame from the router may block data transmission from clients. . To prevent this, the coverage of the CTS frame has to be decreased; this is done by limiting the effective coverage of CTS frame from the router. Using the reverse path established in the network layer, each client determines whether the router is its bidirectional neighbor or not. When the router is not its bidirectional neighbor, CTS will be ignored. If the router is the bidirectional neighbor, the CTS frame will be processed.

From Fig.5 and Fig.6 it is seen that clients D and E are heterogeneous exposed terminals when router B replies CTS to client A. Client C and router F will be blocked after receiving CTS from router B, because they are bidirectional neighbors. However, clients D and E find that router B is not their bidirectional neighbor. Hence, they simply ignore CTS and initialize RTS for data transmission.

Carrier Sensing Along with Cross-layer

In Carrier Sensing, if the channel is idle then transmission occurs without any precaution to prevent collision. If the channel is busy, node waits for a random time.
Carrier sense is a mechanism common to minimize collisions in wireless system. The basic idea of carrier sense is such that before transmitting, a sender listens to the channel and assesses whether a nearby node is transmitting. If no nearby node is transmitting, the sender transmits immediately. If a nearby node is transmitting, the sender defers, waiting for some time after the end of the intervening transmission. Then the sender repeats the same carrier sense-defer process. Carrier sense is a part of the medium access control (MAC) layer. Well-informed MAC decisions are crucial for improving network performance. Deferring a transmission can result in wasting a good transmission opportunity, thereby reducing capacity. Carrier sense avoid these problems, as the sender and receiver are in different locations, and the sender makes the carrier sense decision based on information available to it.[8]

IEEE 802.11 standard specifies two ways to determine if the medium is busy, ie, by physical and virtual carrier sensing functions. IEEE 802.11 specifies that any PHY must provide a technique to sense if the medium is busy. The second is the virtual carrier-sense mechanism that consists of a Network Allocation Vector (NAV) maintained by each client. The NAV tells the client how long the medium will be busy. The client's NAV is updated in response to receiving a frame whose duration field contains a value that exceeds the current NAV value.

The role of the PHY layer carrier sensing is to firmly establish whether the wireless medium is busy or not through a clear channel assessment function. The PHY layer communicates with the next layer,that is the MAC layer about the carrier status. The virtual carrier sensing can be used optionally by a node such that, the transmitting station node, fills the duration field of the frame's MAC header with a value that indicates how long the station is going to use the medium. Now all other nodes within the transmission range of this

transmitting node updates their local network allocation vectors (NAVs) to this time duration and defer their transmissions until their NAV timers count down. After NAV timer reaches zero, it indicates that the medium is virtually not busy anymore. With a hybrid of the virtual carrier sensing and the PHY carrier sensing, IEEE 802.11 can result in reduced collision.[9]

1) *How Carrier Sensing Affects EN*

EN occurs when the carrier- sensing mechanism, which can be physical or virtual , does not allow simultaneous transmissions by non-interfering links. Let IR be the interference range of a link. Any transmission by other links inside the IR of the link will interfere with the transmission of the link. Considering link that are inside the carrier-sensing (CS) range but outside the IR of each other, simultaneous transmissions by the two links are not allowed, even though there is no mutual interference. EN is very common in the 802.11 basic-access mode as well as the RTS/CTS mode, and it is the fundamental factor limiting the network performance due to inefficiency in spatial reuse. The EN problem can be solved as in our approach instead of simply declaring the medium to be busy and respecting the NAV blindly, a node will look at the MAC addresses of the RTS/CTS frame to see if the transmitting link has an interfering relationship with the link the node intends to transmit on. If not, it will simply disregard the RTS/CTS frame. A node also looks at the MAC addresses of the received packet and then selectively respects the physical carrier sensing only if there is an interference relationship between the transmitting link and the link the node intends to transmit on.[10]

2) *How Carrier Sensing Affects HN*

HN occurs when the CS mechanism fails to prevent simultaneous transmissions of interfering links. Nodes could send packets if it is not within the CS range of other nodes. Increasing the CS range alone cannot eliminate HN completely since no matter how large the CS range is, it is still possible that a receiver is inside the CS range of a transmitting link, but its sender is not. In this case, the sender will send DATA to the receiver, but the receiver will not return an ACK, causing the sender to interpret the event as a collision. [10]

Cross-layer Under Different Topology

Three kinds of topology are experimented and compared. In static line topology, the effectiveness of cross-layer approach is validated considering both hidden problem as in Fig. 7 and exposed problem as in Fig. 8. On a star like topology shown in Fig. 9 and random topology, cross-layer approach is compared with the without cross-layer system in terms of various scenarios, including different packet size and data rate. Following, we present these simulations, respectively.

Static line topology includes two conditions to check, i.e., hidden problem and exposed problem. From Fig.7 we see that the node R is the mesh router and nodes C1, C2, C3 and C4 are the clients. CBR traffic flow from C1 to C2 and R to C4 are initiated considering the R to be the hidden node in our simulation.

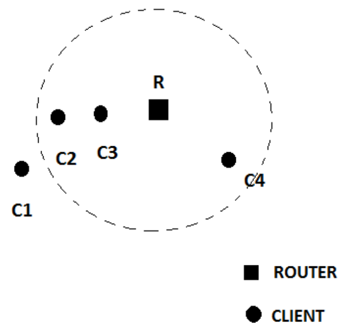

FIG. 7 SET UP FOR SOLVING HIDDEN PROBLEM

To check whether exposed problem is being handled with cross-layering the set up is made with R as router and C1, C2, C3 and C4 as the clients as in Fig.8. CBR traffic is initiated from C1 and R and C2 to C3. Thus from figure we see that the nodes C2 and C3 becomes exposed terminals to node R and C1.

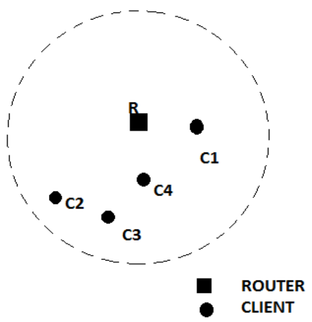

FIG. 8 SET UP FOR SOLVING EXPOSED PROBLEM

In star like topology as shown in Fig.9 the node R is the router and the nodes C1, C2, C3, C4, C5, C6, C7 and C8 are the clients. The flow is between C5 to R and R to C7.

All the topology discussed above is static in nature. In random topology the nodes are in random movement and the flow is taken between any two client nodes and client and router. The system with and without cross-layer is compared for all the three topology cases.

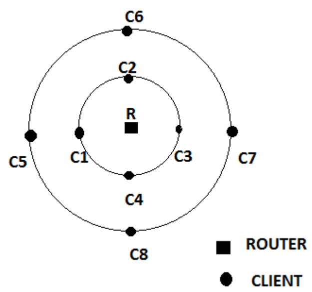

FIG. 9 STAR LIKE TOPOLOGY

In random topology the nodes are in random movement and the flow is taken between any two client nodes and client and router.

In the case of random topology, nodes are in random motion while in static star and static line topology nodes are static in nature. The system with and without cross-layer is compared for all the three topology cases. In the case of random topology, carrier sensing is also included along with cross-layering.

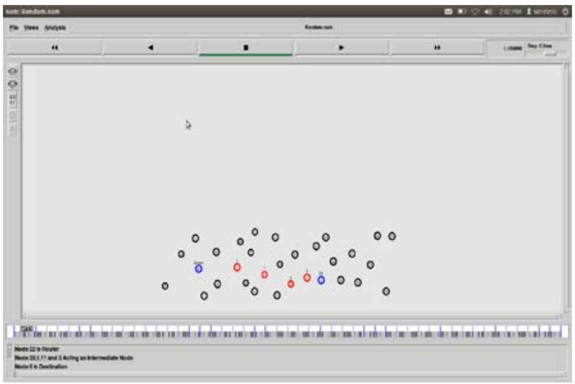

FIG. 10 NODES ARE CREATED DEFINING THEM AS EITHER ROUTER OR CLIENT

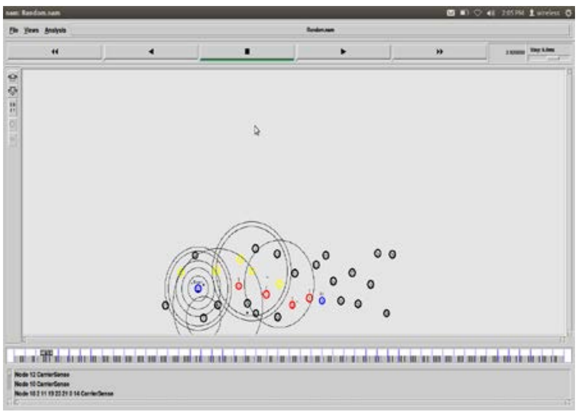

FIG. 11 CARRIER SENSING PROVIDED WITH GROUPING AT DIFFERENT TIME BASED ON ENERGY AND GAIN OF NODES

Carrier Sensing has been included in the simulation in random topology as a modification to the cross-layering approach so as to provide better network efficiency and improvement in performance. Carrier sensing has been included in the simulation with the aid of grouping based on the energy and gain of nodes. Nodes are designated to be carrier sensing nodes in particular group based on the overall energy and gain. These carrier sensing nodes helps in providing aid to reduce the collision by proper routing of packets and thereby improving the performance.

Experiment Results and Simulation

Experimental Setup: In our evaluation, we use NS-2 simulator and the standard IEEE 802.11 protocol as the baseline protocols in comparison with our approach of cross-layer. In our experiments, we take three cases. In all cases clients are of same range of 150m and routers of range 250m.Here we use varying data rate and packet size to compare the throughput for without cross-layer and with cross-layer. We compare the static-star topology, Static line topology and random topology. We adopt a constant bit rate (CBR) traffic model because it is a very popular traffic model and has been widely used in the simulation of the MAC protocol by other researchers. To evaluate network capacity, we consider the throughput, which is defined as the total number of packets delivered to the destination.

Simulation Results: Considering the case of random topology, comparison of with and without cross-layer approach is performed by varying packet size and data rate, we see an increase in throughput for cross –layer approach as shown in Fig. 12. and Fig.13. We have varied the packet size from 128 to 1024 bytes and data rate from 150 to 900kbps.

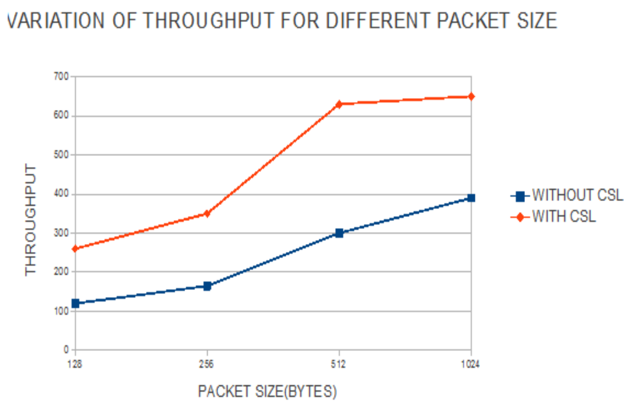

FIG. 12 THROUGHPUT (RANDOM TOPOLOGY) FOR DIFFERENT PACKET SIZE

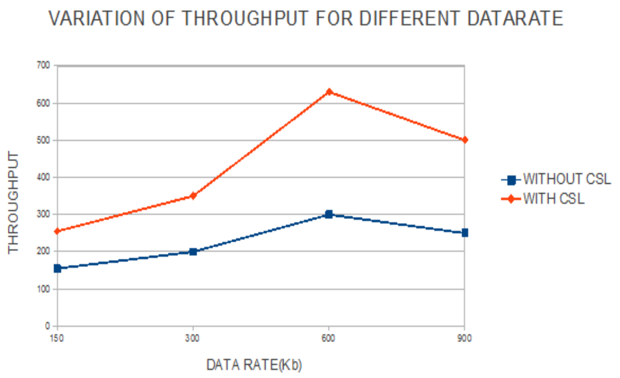

FIG. 13THROUGHPUT (RANDOM TOPOLOGY) FOR DIFFERENT DATARATE

Now considering cases with including carrier sensing along with cross-layer approach we see an increase in packet delivery ratio when compared to system without carrier sensing. Two instances are considered here i.e., one with carrier sensing included in the case of only clients by varying packet size from 200 to 1200 bytes shown in Fig.14 In next case we consider variable range for routers and clients and packet delivery ratio is found with varying packet size from 500 to 1500 bytes as shown in Fig.15.

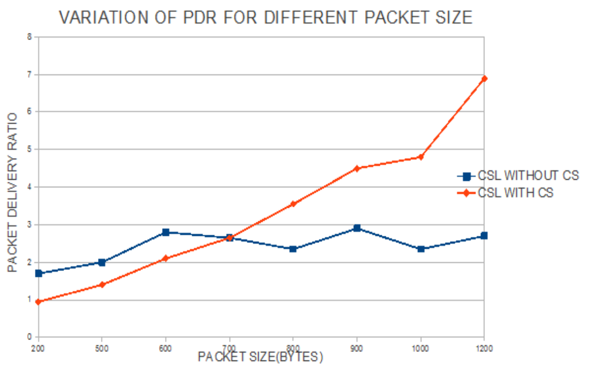

FIG. 14 PACKET DELIVERY RATIO FOR DIFFERENT PACKET SIZE IN RANDOM TOPOLOGY

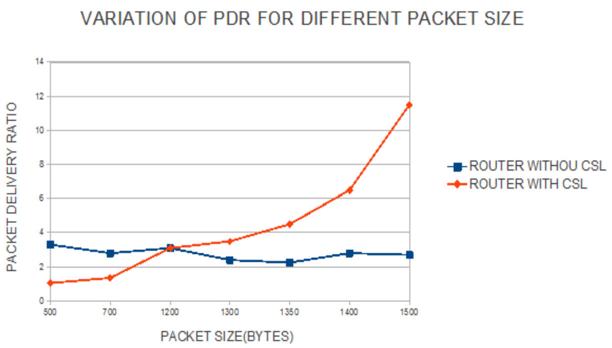

FIG. 15 PACKET DELIVERY RATIO FOR DIFFERENT PACKET SIZE IN RANDOM TOPOLOGY

In the static line topology case where the comparison of with and without cross-layer approach is performed by varying packet size and data rate, we see an increase in throughput for cross –layer approach as shown in Fig. 16. and Fig. 17. for both hidden node scenario and Fig.18. and Fig. 19. shows exposed node scenario. We have varied the packet size from 128 to 1024 bytes and data rate from 150 to 900kbps.

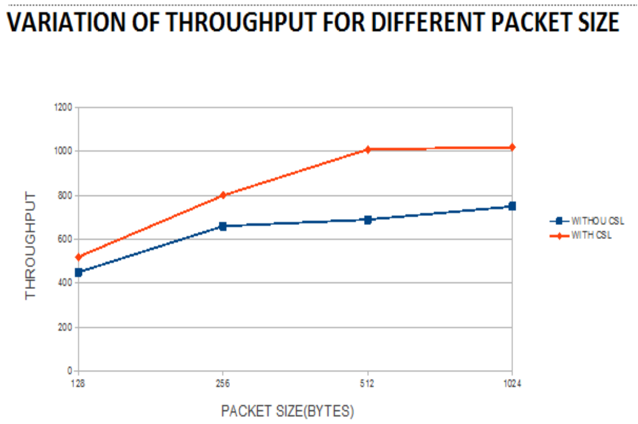

FIG. 16 THROUGHPUT (LINE TOPOLOGY) FOR DIFFERENT PACKET SIZE

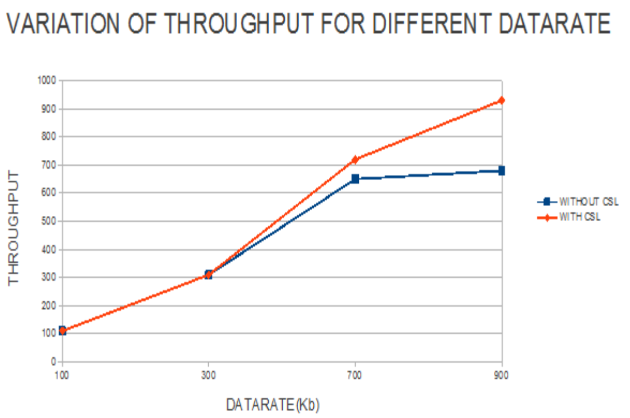

FIG. 17 THROUGHPUT (LINE TOPOLOGY) FOR DIFFERENT DATA RATE

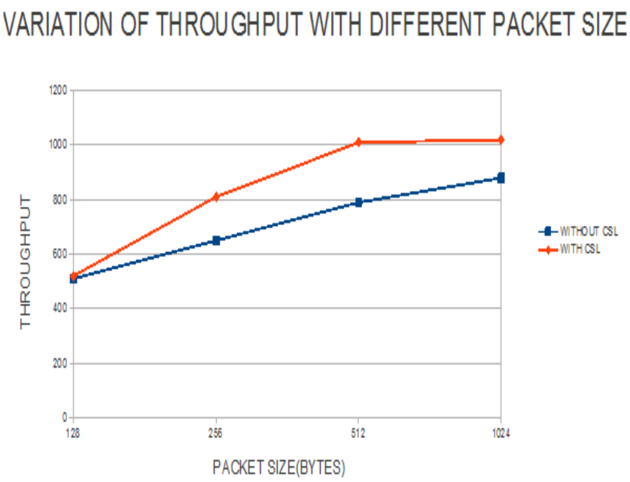

FIG. 18 THROUGHPUT (LINE TOPOLOGY) WITH DIFFERENT PACKET SIZE

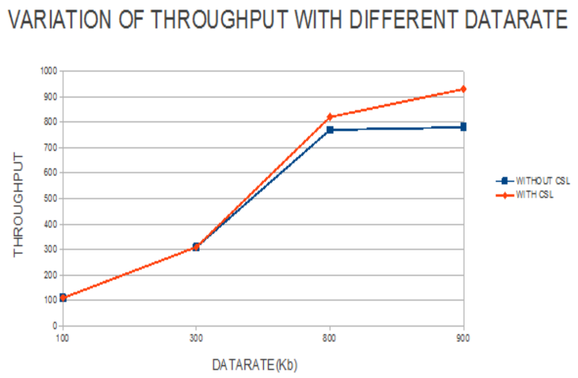

FIG. 19 THROUGHPUT (LINE TOPOLOGY) WITH DIFFERENT DATA RATE

Now considering cases with static star topology, with and without cross-layer approach is compared for varying packet size and data rate. An increase in throughput is seen in both cases for cross-layer approach. Throughput for varying packet size is shown in Fig.20 and throughput for different data rate is shown in Fig.21.

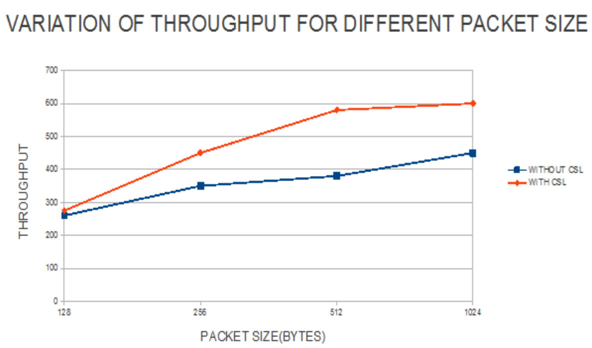

FIG. 20 THROUGHPUT (STAR TOPOLOGY) WITH DIFFERENT PACKET SIZE

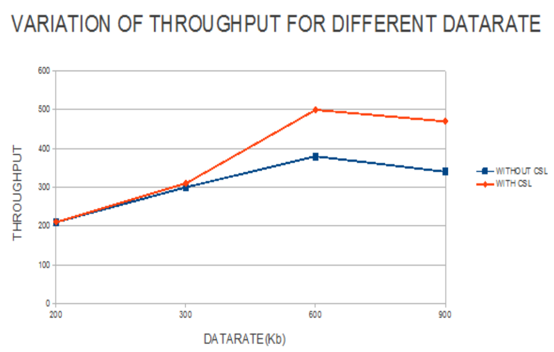

FIG. 21 THROUGHPUT (STAR TOPOLOGY) WITH DIFFERENT DATARATE

Conclusion

From the above simulation results, we see that the network performance could be improved by using a cross-layer approach rather than using single layer independently. The throughput is seen to be higher for cross-layer considering the cases of both varying packet size and data rate. The cross-layer approach appears as best solution for improving network performance, by considering both hidden node as well as exposed node scenario for static line topology. The results have been verified even with static star and random topology. On the whole comparing the static topology system and random topology, we observed that throughput is higher for static topology systems. In random topology system the nodes are at constant movement and so throughput is reduced as there is a chance of packet loss due to random motion. Whereas in the case of static topologies, such as static line and static star throughput is much higher on comparison with the random topology.

Also collisions in the network could be reduced by using carrier sensing approach in addition to the cross-layer approach.

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REFERENCES

A Cross-Layer Approach Handling Link Asymmetry for Wireless Mesh Access Networks Yuefeng Huang, Xinyu Yang, Shuseng Yang, Wei Yu, and Xinwen Fu, *Member, IEEE, IEEE Transactions on vehicular technology, vol. 60,no.3, march 2011*

I. F. Akyildiz and X. Wang, "A survey on wireless mesh networks," *IEEE Commun. Mag., vol. 43, no. 9, pp. S23–S30, Sep. 2005.*

Viral. V. Kapadia, Sudarshan. N. Patel and Rutvij H. Jhaveri, "Comparative study of hidden node problem and solution using different techniques and protocols" , *Journal of computing, volume 2, issue 3, march 2010, issn 2151-961765, https://sites.google.com/site/journalofcomputing/*

Y. Y. Su, S. F. Hwang, and C. R. Dow, "An efficient cluster-based routing algorithm in ad hoc networks with unidirectional links," *J. Inf. Sci. Eng., vol. 24, no. 5, pp. 1409–1428, 2008.*

N. Poojary, S. V. Krishnamurthy, and S. Dao, "Medium access control in a network of ad hoc mobile nodes with heterogeneous power capabilities," in *Proc. IEEE ICC, Helsinki, Finland, Jun. 2001, pp. 872–877.*

M. T. Thai, R. Tiwari, and D. Z. Du, "On construction of virtual backbone in wireless ad hoc networks with unidirectional links," *IEEE Trans. Mobile Comput., vol. 7, no. 9, pp. 1098–1109, Sep. 2008.*

K. M. Mahesh and R. D. Samir, "Routing performance in the presence of unidirectional links in multihop wireless networks," in *Proc. 3rd ACM Int. Symp. Mobile Ad Hoc Netw. Comput., Lausanne, Switzerland, Jun. 2002,*pp. 12–23.

Kyle Jamieson, Bret Hull, Allen Miu, Hari Balakrishnan, "Understanding the Real-World Performance of Carrier Sense", *MIT Computer Science and Artificial Intelligence Laboratory, Proceedings of the ACM SIGCOMM E-WIND Workshop*, pp. 52--57, Philadelphia, PA, 2005

Anucha U. Sylvester, Asagba O. Prince, Ogheneovo E. Edward," Carrier sensing mechanisms: the impact on throughput performance of IEEE 802.11 WLANs" *Scholars March – 2012, Volume – 1, Issue – 1,Article #01,www.setscholars.org, Knowledge is Power,IJAR-CSIT, Research Paper,ISSN: 1839-8480,*

An Chan and Soung Chang Liew, " Merit of PHY-MAC Cross-Layer Carrier Sensing: A MAC-Address-based Physical Carrier Sensing Scheme for Solving Hidden-Node and Exposed-Node Problems in Large-Scale Wi-Fi Networks", *IEEE conf. on local area networks,pp871-878* ,ISSN-0742-1303